# Chapter xx

# Internet of Vehicles and Applications

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## 1.1 Basics of IoV

### 1.1.1 Background and concept

The new era of the Internet of Things is driving the evolution of conventional vehicular ad-hoc networks (VANETs) into the Internet of Vehicles (IoV). IoV refers to the real-time data interaction between vehicles and roads, vehicles and vehicles, as well as vehicles and cities, using mobile communication technology, vehicle navigation system, smart terminal devices and information platform to enable information exchange/interaction and a driving-instruction-controlling network system.

IoV enables the gathering and sharing of information on vehicles, roads and their surrounds. Moreover, it features the processing, computing, sharing and secure release of information onto information platforms, including Internet systems. Based on such information, information platforms can effectively guide and supervise vehicles, and provide abundant multimedia and mobile Internet application services. IoV is an integrated network for supporting intelligent traffic management, intelligent dynamic information service, and intelligent vehicle control, representing a typical application of IoT technology in intelligent transportation system (ITS).

The concept of IoV has been recognized by more and more people in recent years, and it is on a stage of evolving from concept to reality. ITS in Europe and Japan have adopted certain forms of IoV technology. In New Delhi, all 55,000 licensed rickshaws have been fitted with GPS devices so that drivers can be held accountable for their questionable route selection. China's Ministry of Transport has ordered that GPS systems be installed and connected on all long-haul buses and hazmat vehicles by the end of 2011 to ensure good driving habits and reduce the risk for accidents and traffic jams. The Brazilian government has set a goal for all cars in circulation to be fitted with electronic ID chips from its National Automated Vehicle Identification System (Siniav).

IoV is a complex integrated network system, which connects different people within automotives, different automotives and different environment entries in cities. With the rapid development of computation and communication technologies, IoV promises huge commercial interest and research value.

### 1.1.2 Network architecture

IoV consists of complex and heterogeneous wireless network components. A general network architecture is shown in Fig. xx.1. From the view of system, IoV consists of three layers: vehicles, connections and servers/clouds.

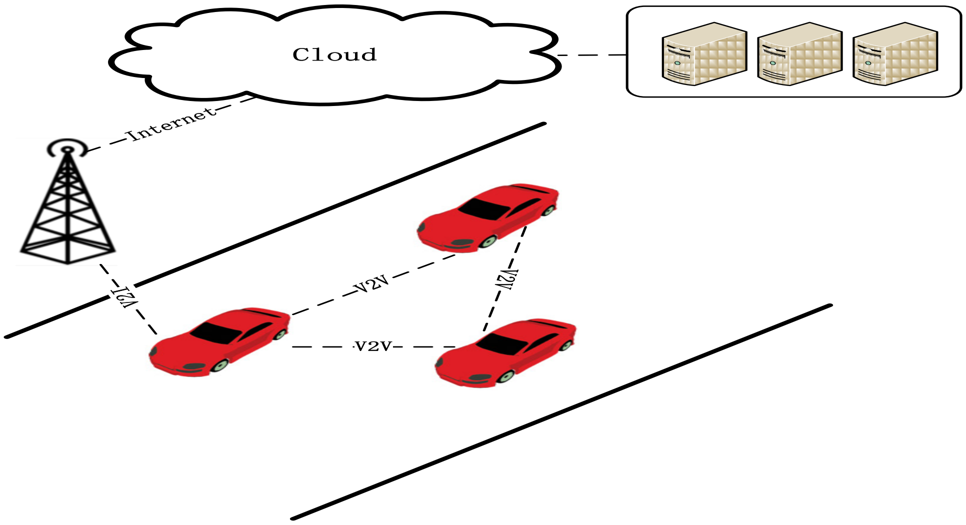

Figure xx.1: The network architecture of IoV

(1) Vehicles in IoV

Vehicles in IoV are intelligent vehicles with complex intra-vehicle systems. Especially, there are various sensors to collect vehicle and driving status, and communication devices to communicate with other vehicles and/or Internet. Of course, an embedded software platform (can be called a vehicular operating system) is necessary to process status information and control all devices.

More and more efforts are being made on research and development of vehicle intelligence. Almost all major vehicle manufactures have started their intelligent vehicle projects, including Toyota, Ford, GM, BMW, Volvo, etc. Also, major IT corporations like Google, Apple, Baidu and Huawei are working on intelligent vehicle systems. Quite a number of vehicles running on the way have been equipped with intelligent systems, although the functionalities related to IoV are still very simple.

In IoV, vehicles play a dual role: they are clients to consume the service from Internet and at the same time they are peers to do distributed computing. Obviously, IoV is a hybrid system with both peer-2-peer and client-server computing paradigms. With peer-2-peer paradigm, vehicles can cooperate and collaborate with each other to realize distributed computing functionalities, such as file sharing, and cooperative driving. With the client-server paradigm, vehicles can use the resource at servers from the Internet. A server can be a ordinary computing node or a cloud data center. With servers, IoV can conduct much more complex applications and tasks.

(2) Connections in IoV

From the view of communications, IoV consists of two different types of wireless wireless connections. Vehicle-to-Vehicle (V2V) communication is used to exchange information among vehicles directly. Wireless links of V2V connect vehicles in an ad hoc way and construct VANETs. The recently defined standard IEEE 802.11p for inter-vehicular communication, designed according to the specific requirements of V2V interaction, constitutes an essential step towards this next phase. However, V2V communication is subject to large network effects. The second type of connection is Vehicle-to-Road (V2R), also called Vehicle-to-Infrastructure (V2I). V2R refers to the information exchange between vehicles and roadside infrastructure equipped with wireless communication technology such as traffic lights or warning signs for road works. Different from V2V, V2R can reach long distance and achieve high scalability. V2R facilitates the interaction of vehicles and roadside units to enhance the aforementioned application scenarios. Moreover, those units may be used as additional hops to augment the reach and thus the overall value of inter-vehicular communication.

With V2V and V2R communications, IoV can realize information exchange among vehicles, roadside infrastructure and also Internet. Then, various applications can be supported by IoV, including Intelligent Transportation Systems and Internet services.

(3) Servers/Clouds in IoV

Servers or cloud data centers may provide various service to vehicles. Servers have powerful computing resource, storage resources, and also more information/data outside vehicles, so advanced or complex IoV applications must involve servers at Internet.

Besides traditional servers, cloud computing based data centers are becoming more and more popular. With cloud computing, more tasks can be conducted via servers in data centers. IoV may also benefit from clouds. For example, traffic management based on clouds should be very attractive. Traffic status data can be collect from vehicles to clouds, via network connections, and then cloud data center can do complex computations and get suitable traffic scheduling solutions.

# 1.2 Characteristics and Challenges

## 1.2.1 Characteristics and challenges

Vehicular networks are mainly composed of vehicle nodes, which behave quite differently from other wireless nodes. Therefore, vehicular network has several characteristics that may affect the design of IoV technologies. Some of the characteristics will bring challenges in IoV technology development, while some others may bring benefit.

(1) Highly dynamic topology. Compared with common mobile nodes, vehicles may move with a quite high speed. This causes the topology of vehicular network change frequently. Such high dynamicity in network topology must been carefully considered in IoV development.

(2) Variable network density. The network density in IoV varies depending on the traffic density, which can be very high in the case of a traffic jam, or very low, as in suburban traffic. Then the network may frequently disconnect.

(3) Large scale network. The network scale could be large in dense urban areas such as the city centre, highways and at the entrance of the big cities

(4) Geographical communication. Compared to other networks that use unicast or multicast where the communication end points are defined by ID or group ID, the vehicular networks often have a new type of communication which addresses geographical areas where packets need to be forwarded (e.g., in safety driving applications).

(5) Predictable mobility. Vehicular network differs from other types of mobile ad hoc networks in which nodes move in a random way, because vehicles are constrained by

road topology and layout and by the requirement to obey road signs and traffic lights and to respond to other moving vehicles leading to predictability in term of their mobility.

(6) Sufficient energy and storage. A common characteristic of nodes in vehicular networks is that nodes have ample energy and computing power (including both storage and processing), since nodes are cars instead of small handheld devices.

(7) Various communications environments. Vehicular networks are usually operated in two typical communications environments. In highway traffic scenarios, the environment is relatively simple and straightforward (e.g., constrained one-dimensional movement); while in city conditions it becomes much more complex. The streets in a city are often separated by buildings, trees and other obstacles. Therefore, there isn’t always a direct line of communications in the direction of intended data communication.

### 1.2.2 Challenges in IoV

The objective of IoV is to integrate multiple users, multiple vehicles, multiple things and multiple networks, to always provide the best connected communication capability that is manageable, controllable, operational, and credible. It composes a really complex system. Moreover, the applications of IoV are quite different from those of other networks, and consequently many special requirements arise. Both these two aspects bring new technical challenges to IoV research and development.

(1) Poor network connectivity and stability. Due to the high mobility and rapid changes of topology, which lead to a frequent network disconnections and link failures, message loss should be common. Then, how to elongate the life of communication links is always challenging.

(2) Hard delay constraints. Many IoV applications have hard delay constraints, although they may not require high data rate or bandwidth. For example, in an automatic

highway system, when brake event happens, the message should be transferred and arrived in a certain time to avoid car crash. In this kind of applications, instead of average delay, the maximum delay will be crucial.

(3) High reliability requirements. Transportation and driving related applications are usually safety sensitive. Obviously, such applications requirement is high reliability. However, due to complex network architecture, large network scale and poor stability of network topology, achieving high reliability in IoV is far from trivial. Special design needs to be conducted in various layers, from networking protocols to applications.

(4) High scalability requirements. High scalability is another big challenge in IoV. As mentioned before, IoV is usually very large in terms of node number and deployment territory. Such large scale certainly requires high scalability in IoV technologies.

(5) Security and privacy. Keeping a reasonable balance between the security and privacy is one of the main challenges in IoV. The receipt of trustworthy information from its source is important for the receiver. However, this trusted information can violate the privacy needs of the sender.

(6) Service sustainability. Assuring the sustainability of service providing in IoV is still a challenging task, calling for high intelligence methods, as well as a friendly network mechanism design. There are challenges in adjusting all vehicles to provide sustainable services over heterogeneous networks in real-time, subject to limited network bandwidth, mixed wireless access, lower service platforms, and a complex city environment.

# 1.3 Enabling Technologies

IoV is a complex system with heterogeneous network components, large scale and diverse applications. Then, various technologies, especially networking technologies are necessary to make IoV applications workable. In the following, we introduce these enabling technologies according to network layers: MAC layer and routing layer. In routing layer, we introduce both unicast oriented routing protocols and broadcasting based dissemination algorithms. Of course, broadcasting based information dissemination can also be viewed as application layer protocols. Anyway, this does not affect the understanding of these algorithms.

## 1.3.1 MAC Protocols and Standards

There are quite lot works on designing special MAC protocols for IoV or more precisely VANETs. Almost all VANET MAC protocols are based on the basic wireless communication standard IEEE 802.11. Therefore, we introduce IEEE 802.11 first, and then discuss the extension to its variants for VANETs.

- IEEE 802.11

According to the IEEE's technical paper, a wireless LAN (WLAN or WiFi) is a data transmission system designed to provide location-independent network access between computing devices by using radio waves rather than a cable infrastructure.

The IEEE LAN committee raised a series of Wireless Local Area Network (WLAN) standards. Collectively, these wireless standards are identified as the 802.11 standard [1]. This specification was ratified by IEEE in 1997 firstly. Then various amendments have been made to the 802.11 standard, as shown in Table xx.1 .

Table xx.1 IEEE 802.11 Standards

| Protocol | Release date | Frequency (GHz) | Maximum data rate | Modulation | Approximate range | |
|---|---|---|---|---|---|---|
| | | | | | Indoor(m) | Outdoor(m) |
| 801.11 | 1997 | 2.4 | 2Mbit/s | DSSS/FHSS | 20 | 100 |
| 802.11a | 1999 | 5 | 54Mbit/s | OFDM | 35 | 120 |
| 802.11b | 1999 | 2.4 | 11Mbit/s | DSSS | 35 | 140 |
| 802.11g | 2003 | 2.4 | 54Mbit/s | OFDM/DSSS | 38 | 140 |
| 802.11n | 2009 | 2.4/5 | 600Mbit/s (40MHz*4 MIMO) | OFDM | 70 | 250 |
| 802.11ac | 2011 | 5 | 867Mbps, 1.73 Gbps, 3.47 Gbps, 6.93 Gbps (8 MIMO, 160MHz) | OFDM | 35 | |
| 802.11ad | 2012 | 60 | Up to 6,912 Mbit/s | SC/OFDM | 60 | 100 |

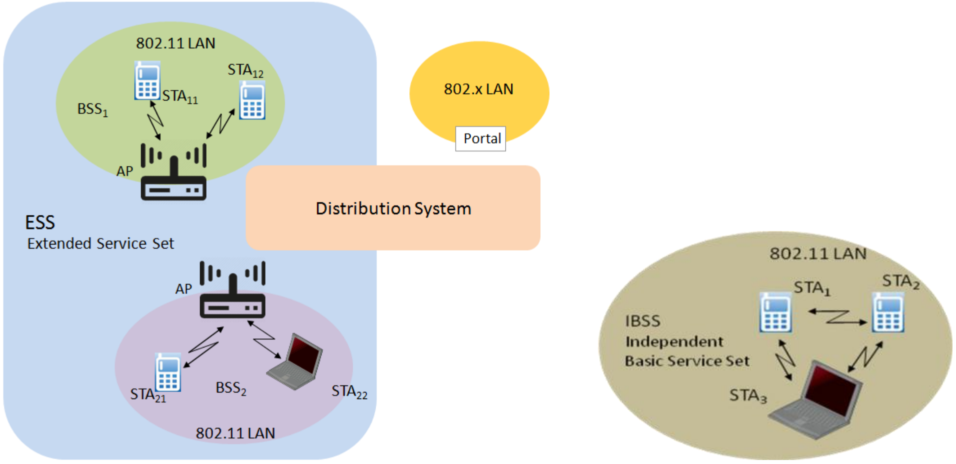

Figure xx.2: The network architecture of IEEE 802.11

As shown in Fig. xx.2, an IEEE 802.11 network consists of two types of entities: mobile station (STA) and access point (AP). AP refers to the device integrated into the wireless LAN and the distribution system. STA refers to the client terminal with access mechanisms to the wireless medium and radio contact to the AP. There may be also a "portal", which bridges a WLAN to other (wired) networks. A Basic Service Set (BSS) is the basic building functional block of an IEEE 802.11 LAN, which consists of an AP and a set of STAs. Multiple BSSs may be connected into one LAN to extend the cover a large area, and such set of BSSs is called Extended Service Set (ESS). An IBSS is a special type of IEEE 802.11 LAN, where a wireless client can connect with each other via point-to-point mode.

IEEE 802.11's frequency band is either the 2.4-GHz (specifically, 2.4000 to 2.4835GHz) or the 5.0-GHz (specifically, 5.150 to 5.825GHz) spectrum bands. The 2.4 GHz band supports a total of 14 channels, though the FCC limits this to 11 channels in the United States. The 5-GHz band is regulated and thus generally free of interference. However, signals at this frequency suffer from poor range and are easily obstructed by intermediary objects. The less-often used 5-GHz band supports up to 12 non-overlapping channels (in U.S.), and is further separated into three sub-bands (with four channels each).

- IEEE 802.11p/WAVE

Vehicular networks have attracted more and more attention without any doubt as the number of vehicles grows so fast. Therefore several working groups have been set to make the communication protocols, such as the IEEE 1609 working group, the IEEE 802.11p task group.

IEEE 802.11p is known as an amendment to the IEEE Std 802.11 for wireless access in vehicular environments. Because of the high mobility of vehicles, the original protocols in IEEE std 802.11 are not suitable to this environment any more. To address this issue, IEEE working group has come up with a protocol stack known as IEEE 802.11p (Wireless Access in Vehicular Environment, WAVE) [2] to handle the problem of reliable connection.

WAVE extends the ASTM Standard E2213-03 (known as DSRC) to operate in a rapidly varying environment and exchange messages without joining a basic service set (BSS). It uses the Enhanced Distributed Channel Access (EDCA) MAC sub-layer protocol designed based on that of the IEEE 802.11e with some modifications, while the physical layer is OFDM (Orthogonal Frequency Division Modulation) as used in IEEE 802.11a. Besides, it defines the signaling techniques and interface functions used by stations communicating outside of the context of a BSS that are controlled by the IEEE 802.11 MAC.

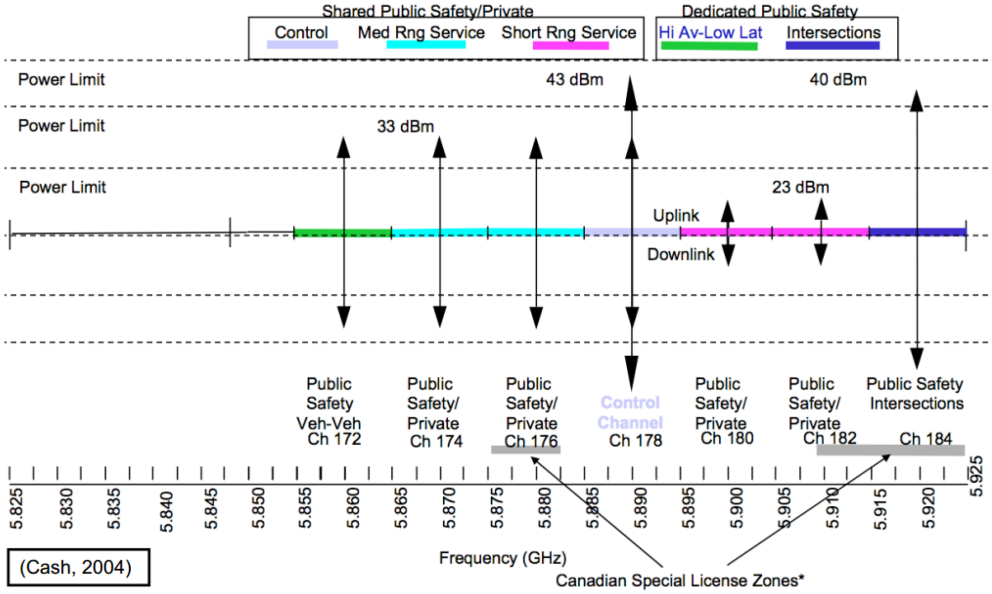

Figure xx.3: Channel allocation in WAVE [2]

Fig. xx.3 shows the channel allocation in IEEE 802.11p. The 75 MHz band is divided into one Control Channel (CCH) and six Service Channels (SCHs). Two small and two medium zone service channels are designated for extended data transfer. Two service channels are designated for special safety critical applications. Public safety applications and messages have priority in all channels. Firstly, RSU announces to OBUs 10 times per second the applications it supports on which channels. OBU listens on channel 172, then authenticates RSU digital signature. OBU should execute safety apps first and switches channels, then executes non-safety apps. At last OBU returns to channel 172 and listens to the channel again.

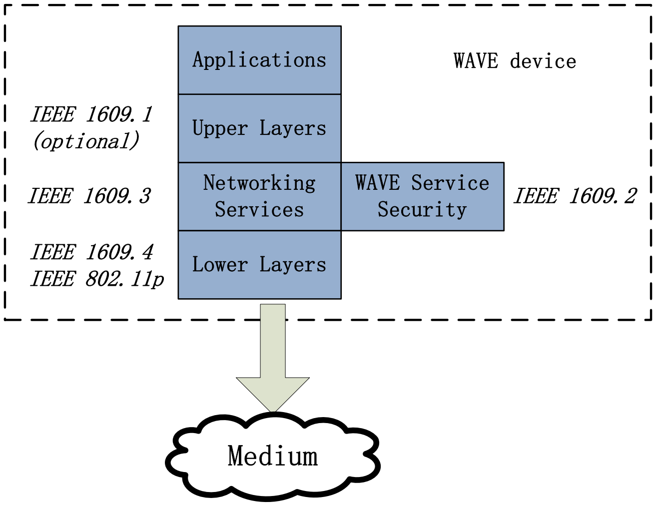

Figure xx.4: IEEE 1609 standard family

On top of IEEE 802.11p, IEEE 1609 defines an architecture and a complementary, standardized set of services and interfaces for vehicle-related wireless communications [3]. It provides foundations for a broad range of applications in the transportation environment, such as vehicle safety, automated tolling, enhanced navigation, traffic management. The architecture of IEEE 1609 protocols is shown in Fig. xx-4.

IEEE 1609.0 describes the WAVE architecture and services necessary for multi-channel DSRC/WAVE devices to communicate in a mobile vehicular environment. IEEE 1609.1 describes key components of WAVE system architecture and defines data flows and resources. It also defines command message formats and data storage formats, and specifies the types of devices that may by supported by OBU. IEEE 1609.2 collects the security processing requirements necessary for WAVE system operation. IEEE 1609.3 specifies network and transport layer services, including addressing and routing, in support of secure WAVE data exchange. It also defines Wave Short Messages, providing an efficient WAVE-specific alternative to IPv6 (Internet Protocol version 6) that can be directly supported by applications [3]. IEEE 1609.4 Specify MAC sublayer functions and services for supporting multichannel wireless connectivity between WAVE devices. It control the operation of upper layer data transfers across multiple channels without requiring knowledge of PHY parameters, and it also describes multi-channel operation channel routing and switching for different scenarios. IEEE 1609.11defines the services and secure message formats necessary to support secure electronic payments. IEEE 1609.12 indicates identifier values that have been allocated for use by WAVE systems.

Besides the standard protocols, researchers have also conducted study to extend and improve the performance of MAC protocols. Based on the latest standard draft IEEE 802.11p and IEEE 1609.4, Wang et al. [4] proposed a variable CCH interval (VCI) multichannel medium access control (MAC) scheme, which can dynamically adjust the length ratio between CCH and SCHs. The scheme also introduces a multichannel coordination mechanism to provide contention-free access of SCHs. Markov modeling is conducted to optimize the intervals based on the traffic condition. Dang et al. [5] proposed a new multi-channel MAC for VANETs, named HER-MAC, which supports both TDMA and CSMA multiple access schemes. The HER-MAC allows vehicle nodes to send safety messages without collision on the Control CHannel (CCH) within their reserved time slots and to utilize the SCH resources during the control channel interval (CCHI) for the non-safety message transmissions.

### 1.3.2 Routing Protocols

Routing protocol is the network layer protocol to provide end-to-end message delivery service. Although many IoV applications are executed in a broadcasting way, there are still applications requiring unicast oriented multi-hop communications. Unfortunately, to the best of our knowledge, there is still no specific routing protocol for IoV proposed. Therefore, routing protocols for common mobile ad hoc networks (MANETs) have to be used if unicast of messages is necessary.

Routing for MANETs has been always a hot topic and many protocols have been proposed, including DSR and DSDV. Among others, AODV and OLSR are the most popular and widely accepted. Also, IEEE 802.11s provides multi-hop forwarding mechanism for 802.11, and can also be used for message routing in unicast.

- AODV

Ad hoc On-Demand Distance Vector (AODV) routing [6] is a routing protocol for mobile or other wireless ad hoc networks. It uses an on-demand approach for finding routes. The source node and the intermediate nodes store the next-hop information corresponding to each flow for data packet transmission. The source node floods the RouteRequest packet in the network when a route is not available for the desired destination. When an intermediate node receives a RouteRequest, it either forwards the packet or prepares a RouteReply if it has a valid route to the destination. AODV uses a destination sequence number (DestSeqNum) to determine an up-to-date path to the destination. A node updates its path information only if the DestSeqNum of the current packet received is greater than or equal to the last DestSeqNum stored at the node with smaller hopcount.

- OLSR

The Optimized Link State Routing Protocol (OLSR) [7] is a proactive link-state routing protocol, which uses hello and topology control (TC) messages to discover and then disseminate link state information throughout the ad hoc network. Individual nodes use this topology information to compute next hop destinations for all nodes in the network using shortest hop forwarding paths.

The OLSR protocol uses a link-state algorithm to proactively determine the most efficient path between nodes. The key point of OLSR lies in the dynamic Multi-Point Relay (MPR) technique, which selects only a subset of neighboring nodes to relay data instead of every node acting as a relay. MPRs are elected in such a way that every node can communicate with a MPR within one hop. The localized network information is shared between MPRs to maintain network-wide routing paths. This allows every MPR to have a complete routing table while simultaneously minimizing the number of topology control messages.

- Multi-hop-MAC Protocol (IEEE 802.11s)

IEEE 802.11s is an IEEE 802.11 amendment for mesh networking, defining how wireless devices can interconnect to create a WLAN mesh network, which may be used for static topologies and ad hoc networks. IEEE 802.11s supports both broadcast/multicast and unicast delivery using "radio-aware metrics over self-configuring multi-hop topologies." An 802.11s mesh network device is labeled as Mesh Station (mesh STA). Mesh STAs form mesh links with one another, over which mesh paths can be established using a routing protocol. 802.11s defines a default mandatory routing protocol (Hybrid Wireless Mesh Protocol, or HWMP), yet allows vendors to operate using alternate protocols. HWMP is a combination of AODV and tree-based routing.

### 1.3.3 Broadcasting and Information Dissemination

Information dissemination is the transportation of information to the intended recipients while satisfying certain requirements such as delay, reliability, and so on. These requirements vary, depending upon the information being disseminated. The main issue for information dissemination is that a simple query or on demand methodology for disseminating information does not suit VANETs due to their high mobility and network partitions. According different dissemination schemes, information dissemination algorithms can be classified into four types as follows.

- V2V based

In these algorithms, information is disseminated among vehicles via V2V connections. Yan et al. [8] focused on the problem that a sender needs to disseminate information to $M$ recipients and collect $M$ receipts in an interested area consisting of $k$ roads, which is solved by a processor scheduling scheme. In [9], the dissemination protocol is based on the probability that a vehicle will meet an event. TIGeR [10] is a traffic-aware intersection-based geographical routing protocol, where only nodes at intersections make routing decision based on vehicular traffic information of different roads and the road's angle with respect to the destination. VITP [11] is designed to provide car drivers with time-sensitive information about traffic conditions and roadside facilities.

As in other wireless networks, clustering has been used to reduce communications cost in vehicular networks. Chu et al. [12] designed a cluster based overlay solution, which creates a mobility-adaptive cluster to represent local traffic information and selects the optimal relay node of the inter-cluster forwarding pair to increase the efficiency. DPP [13] controls message propagation direction by using limited-range packet radios and attribute-based routing. Chen et al. [14] proposed to make use of navigation route for connected dominating set (CDS) construction. CDS is a popular approach for information dissemination in ad hoc networks. The algorithm in [14] tries to construct stable CDS so as to reduce CDS maintenance overhead and message forwarding cost.

- V2R based

In these algorithms, roadside infrastructure is involved in information dissemination. In [15], based on the orthogonality of the encoded sets of rateless codes, portions of the information can be disseminated even if this has not been decoded yet. Kone et al. [16] used measurements of a fleet of WiFi-enabled vehicles to design information dissemination mechanism that scales with device density. Khabbaz [17] proposed a multiserver queuing model to accurately calculate the dynamics of vehicular networks. SADV [18] includes static nodes at intersections to store packets and transmit them when the optimal delivery path becomes available.

- DTN based

V2V or V2R algorithms above usually rely on continuous network connectivity. However, high mobility of vehicles may result in network partitions frequently. Delay/Disruption Tolerant Network (DTN) is the technique to handle such a challenge by routing packets in "store and forward" mode [19], where data is incrementally moved and stored throughout the network in hopes that it will eventually reach its destination. The key point of DTN lies in how to maximize the probability of a message being successfully transferred.

Baccelli et al. [20] analyzed the effect of vehicle density on information propagation speed, and proved that, under a certain threshold, information propagates on average at vehicle speed, while above this threshold, information propagates dramatically faster at a speed that increases quasi-exponentially when the vehicle density increases. Interestingly, Agarwal et al. [21] also derived both upper and lower bounds on the average message propagation speed against traffic density, by exploiting a connection with the classical pattern-matching problem in probability theory.

## 1.4 Applications

The applications of IoV are quite diverse. According to functionalities, we categorize them into three major classes. A detailed taxonomy is shown in Fig. xx,5.

### 1.4.1 Driving safety related

Driving safety related applications mainly refer to cooperative collision avoidance systems (CCAS) [22], which extend collisions avoidance system (CAS) by sharing CAS information among neighboring vehicles, via V2V communications usually [23][24].

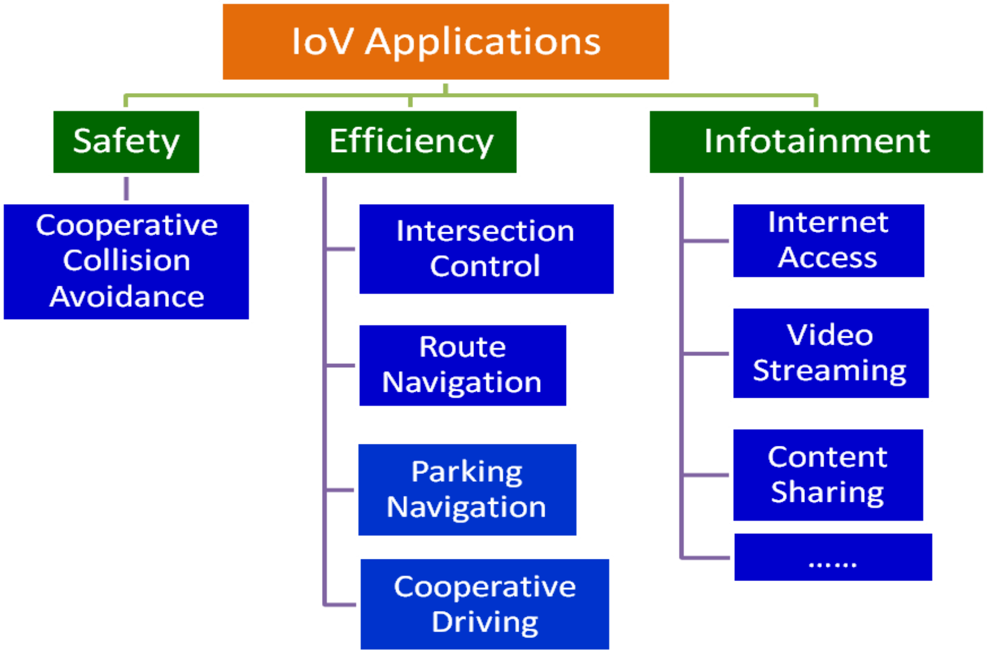

Figure xx.5: A taxonomy of IoT applications

CAS, also known as precrash system, forward collision warning system or collision mitigating system, uses radar or other sensors (like laser and camera) to detect an imminent crash, and then provide a warning to the driver or take braking/steering action directly. CCAS adopts cooperation among vehicles to mitigate collisions among multiple vehicles, as shown in Fig. xx.6.

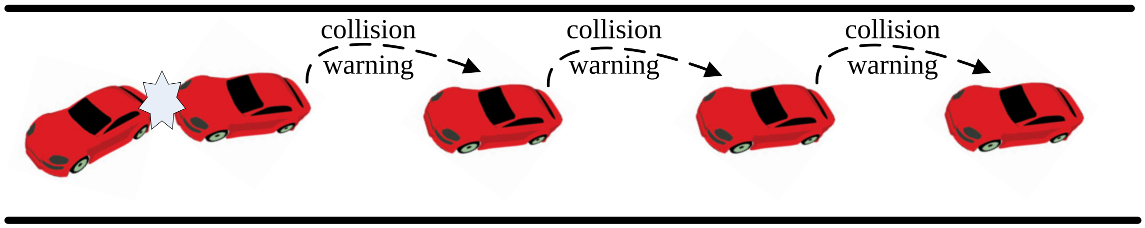

Figure xx.6: Cooperative collision avoidance system

CarTALK 2000 [25] is a quite early work that involves CCAS. Techniques and algorithms were developed to test and assess cooperative driver assistance applications, including CCAS function. Yang et al. [26] defined special congestion control policies and redundant detection mechanism for emergency warning messages so as to achieve low delay and low communication cost. Taleb et al. [27] designed a risk-aware MAC protocol for CCAS, where the medium access delay of each vehicle is set as a function of its emergency level and vehicles in high emergency situations can disseminate warning messages with shorter delay so as to minimize chain collisions.

Milanés et al. [28] proposed a V2R based vehicle control system. A fuzzy-based control algorithm is in charge of determining each vehicle's safe and comfortable distance to avoid collision. Maruoka et al. [29] focused on collision judgment. The authors proposed a judgment algorithm based on estimated relative positions and potential collision indicated area, which can reduce false warnings and unnecessary warnings.

### 1.4.2 Transportation efficiency related

Efficiency is one of the major concerns of transportation management. Vehicular network technology brings new possibility of efficiency improvement. As shown in Fig. xx.6, existing transportation efficiency related applications can be further classified into three categories: intersection control, route navigation, parking navigation, and cooperative driving.

1) Intersection control

Traffic control at intersections has been always a key issue for ITS. The key point is how to schedule traffic signal efficiently according to traffic volume information so as to reduce waiting time and improve fairness. There have been many algorithms or systems proposed for intelligent intersection control, which can be categorized as in Fig. xx.7.

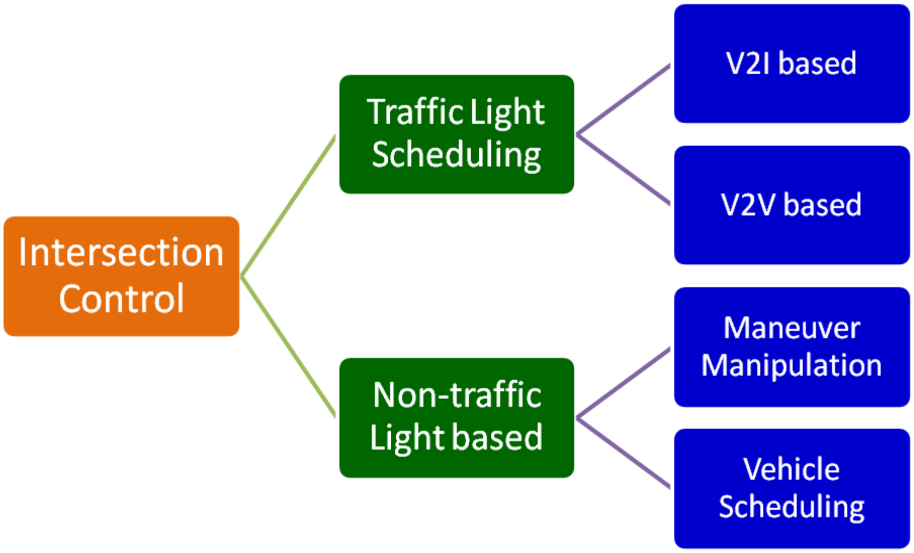

Figure xx.7: A Taxonomy of intelligent intersection control algorithms

Most existing works on intersection control are traffic light based and the key issue is to determine a good signal scheduling plan. In early works, road detectors are used to collect traffic volume information and traffic signal plan is changed in adaptation to the varying traffic conditions. Systems such as SCOOT [30] and SCATS [31] have been deployed for many years.

Traffic light scheduling based on vehicular networks is the new stage of intelligent intersection control. Detailed vehicle information, including id, speed and position, are collected via V2V or V2I communications. Then, more accurate and efficient scheduling can be achieved.

V2I based traffic light scheduling is widely studied. In [32][33], a controller node is placed at the intersection to collect queue length information and computer proper cycle time of traffic signal via the Webster formula. In addition to queue length information, priority of vehicles is considered in [34], and traffic signal is scheduled with quality-of-service provisioning. In some other works, signal scheduling is modeled as a combinatorial optimization problem to find an optimal scheduling plan of traffic signal. To solve such a problem, various methods such as dynamic programming (DP) [35][36], branch-and-bound [37] and linear programming [38] have been applied. Some researchers introduce intelligent algorithms to traffic light scheduling, including fuzzy logic based scheduling [39], Q-learning based scheduling [40] [41].

V2V based adaptive traffic light control is presented in [42]. This system reduce communication cost by clustering vehicles approaching the intersection. The density of vehicles within the cluster is computed using a clustering algorithm and sent to the traffic signal controls to set the timing cycle.

There are also intersection control approaches without using traffic lights. In maneuver manipulation based algorithms [43][44][45][28], the driving behaviors of vehicles are completely controlled by the intersection controller, Which calculates the optimal trajectory for each vehicle so that vehicles can safely pass the intersection without colliding with each other. Since the speed and position of each vehicle need to be accurately calculated, the optimization is very complex, especially when the number of vehicles is large.

In vehicle scheduling algorithms, there is also no traffic light involved, but the different from maneuver based ones, these algorithms schedule only the permissions to pass intersection rather than the driving behaviors. Dresner et al. [46][47] proposed a reservation-based intersection control system, where vehicles interacts with intersection controller through wireless communication to get reservations for passing. According to the traffic condition and current reservations, intersection controller decides whether to accept a new reservation request or not. Wu et al. [48] adopted the distributed mutual exclusion approach to realize vehicle scheduling without traffic light used. Ferreira et al. [49] proposed the notion of "virtual traffic light", where some vehicle is elected as the traffic light node via V2V communications.

2) Route navigation

Vehicular network based navigation is studied to avoid the drawbacks of GPS based or similar navigations. Chen et al. [50] proposed to construct navigation route with considering real-time traffic information and fuel consumption.

Collins et al. [51] proposed a route selection algorithm that can cope with traffic congestion by optimizing road utility. VSPN [52] is a privacy-preserving navigation scheme that utilizes speed data and road conditions collected by RSUs to guide vehicles. Leontiadis et al. [53] designed a system based on crowd-sourcing traffic information in an ad hoc manner.

3) Parking navigation

Finding an available parking slot in an urban environment with the help of vehicular networks is also an interesting problem. Verroios et al. [54] formulated the problem as a Time-Varying Travelling Salesman problem and proposed an approach for computing the route that a vehicle must traverse to visit all parking spaces known to be available.

Lu et al. [55] designed a conditional privacy preservation mechanism in smart parking scheme. In [56], atomic information, aggregated information and overlay grid are used to discover free parking places.

### 4) Cooperative driving

Cooperative driving technology is used to coordinate a queue of vehicles to make them drive as one vehicle. It can improve the energy efficiency obviously.

Gehring et al. [57] proposed practical results of a longitudinal control for truck platooning. Based on distance measurement between vehicles, a robust platoon controller is designed based on sliding mode control. Seiler et al. [58] examined how the disturbance to error gain for an entire platoon scales with the number of vehicles. Cooperative driving at blind crossings is studied in [59]. A concept of safety driving patterns is proposed to represent the collision-free movements of vehicles at crossings. In [60], a leaderless approach is proposed based on a model for interacting agents with bidirectional and unidirectional, time-dependent communication.

### 1.4.3 Infotainment services

Infotainment services include mainly Internet access service and file sharing among vehicles, especially video sharing. Fig. xx.8 shows an example of video sharing.

Vehicle-to-Internet communication is a challenging task. A QoS framework to ensure data forwarding to Internet in gateway-free area in highway scenario is proposed in [61]. It consists of a proxy-based vehicle to Internet protocol, with a prediction-based routing algorithm and IEEE 802.11p EDCA scheme.

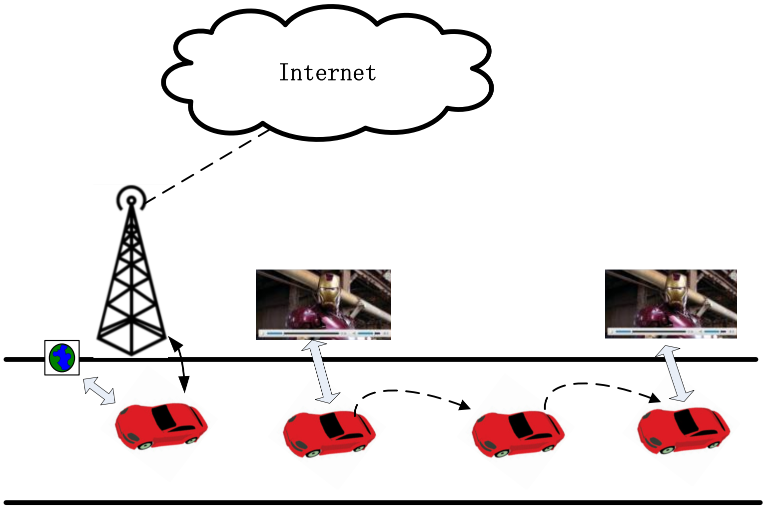

Figure xx.8: An example of video services

Video streaming over VANET has attracted more and more attention. Asefi et al. [62] introduced a quality-driven scheme for seamless delivery of video packets in urban VANET scenarios, which includes routing, mobility management mechanisms based on Mobile IPv6. Xing et al. [63] proposed an adaptive video streaming scheme for video streaming services in the highway scenario. Relying on cooperative relay among vehicles, a vehicle can download video data using a direct link or a multihop path to the RSUs. The proposed scheme can request an appropriate number of video enhancement layers to improve video quality of experience.

Razzaq et al. [64] proposed a robust scheme for SVC-based streaming over an urban VANET with path diversity and network coding. The scheme calculates the quality of all candidate paths based on grey relational analysis and then assigns paths to different layers according to their importance. Nearby nodes along the transmission path may recode their received packets and stores them in buffers for recovering lost packets.

Guo et al. [65] proposed a V2V live video streaming named V3, which addresses the challenges of V2V video streaming by incorporating a novel signaling mechanism to continuously trigger vehicles into video sources. It also adopts a store-carry-and-forward approach to transmit video data in partitioned network environments.

Lee et al. [66] proposed a mechanism called Cooperative Video Streaming over Vehicular Networks (CVS-VN). It adopts a new video codec called Co-SVC-MDC, which divides the multimedia stream into several descriptions. The requester can get the basic QoS for multimedia display via the requester's 3G/3.5G network channel. Other low-priority descriptions are scheduled to be transmitted via helpers' 3G/3.5G network channels.

Seferoglu et al. [67] proposed video schemes for network code selection and packet scheduling by considering the importance-deadlines of video packets, the network state, and packets received in the neighborhood. Xie et al. [68] studied the performance of video streaming under different data forwarding and buffer management schemes, in highway environments without frequent link disconnections and persistent network partitions.

## 1.5 Summary and Future Directions

IoV is an evolution of VANETs and an extension of Internet. As an important part of IoT, IoV involves several different research fields, including wireless communication /networking, mobile computing, cloud computing, intelligent transportation, and even auto-pilot vehicles.

Networking technologies are the basis of IoV. There have been many efforts on the study and standardization of communication protocols for IoV, especially for the VANET part. IEEE 802.11p and related protocol family should be the future of IoV communication protocols. In the level of routing and data dissemination, both broadcasting based paradigm and point-to-point paradigm are necessary, and they are suitable for quite different applications.

Applications are the driving power of IoV. IoV applications are quite diverse, including driving safety and efficiency service, intelligent traffic management, and informative services. Some applications, e.g. traffic light scheduling, have emerge before IoV, but IoV will certainly bring revolutionary changes in both technology and functionality. More applications are totally new. For example cooperative driving is not possible without vehicular communications. Many applications have been proposed and some have been deployed. Of course, more and more applications will emerge in future.

Of course, IoV is still in its initial stage and there are many technical problems to be addressed before IoV can be widely accepted and deployed. Among others, the following directions should be worthy further study in future.

(1) Efficient information routing and dissemination

Although specialized MAC protocol family has been developed for IoV, especially VANETs, multi-hop communications in IoV is still a hard task. High mobility and weak connection makes information forwarding and dissemination far from trivial. Researchers are putting more and more efforts on this topic, it lags far behind MAC layer technology. More precisely, how to routing messages in network level with mechanism suitable for vehicular environments is a very interesting topic. This includes both broadcasting based information dissemination and unicast based message delivery. Widely accepted routing or dissemination protocol does not appear yet.

(2) Communications based on Software-Defined Networking (SDN)

There has been a little work on software-defined vehicular networks. However, it is far from enough. SDN is naturally suitable for IoV environment, because vehicle are forwarders and at the same time computing nodes. Realizing SDN paradigm is easy, but the difficulty lies in suitable link control and allocation algorithms. Different from wired WAN environments, or even traditional ad hoc networks, vehicular links are more dynamic, so how to control and allocate such resources is very challenging. Underlying technical issues include: vehicular link modeling and representing, allocation of dynamic changing link resources via network controller, forwarding rule delivery and management, etc.

(3) Communications based on Named Data Networking (NDN)

Similar to SDN, NDN is another promising networking technology for future Internet. It is even more revolutionary in terms of routing mechanism. Applications of IoV usually involve transportation information, which is naturally propagated to non-predefined vehicles according to its content. Such a characteristic makes NDN a very suitable technology for IoV. However, NDN in IoV is not studied widely and there are many open problems to be considered. Possible directions include transportation data naming and organizing, design of data request and forwarding table for vehicle nodes, message caching at vehicles, application specific NDN algorithms, etc.

(4) Generic coordination mechanisms

IoV is network based and all applications may involve coordination among vehicles. Synchronization and agreement are used in distributed applications, like cooperative driving, cooperative intersection control Current distributed coordination is usually embedded into application logics. Such design is not good in terms of protocol/algorithm design. Decoupling coordination and application and realizing modularized design should be a good choice. Therefore, generic coordination algorithms even middleware platform will be very interesting.

(5) Traffic data processing

Besides node coordination, traffic data processing should be another topic that may rise generic techniques or platforms in the middleware level. With more and more vehicles are equipped with intelligent devices and also more and more roadside units are deployed, vehicular data will increase in an explosive way, like in other fields of IoT. On the one hand, big traffic data provides more knowledge for IoV and may help improve the performance of IoV applications or even rise new ones. On the other hand, traffic data processing itself rise new challenges. Besides general big data techniques, IoV specific data processing techniques should be considered. Especially, cloud based traffic data processing is of special interest.

(6) New applications

New applications of IoV are always desirable. With fast development of enabling technologies and user requirements, many new IoV applications will emerge. Although such applications are still in the categories of driving safety and efficiency, traffic management and informative services, they may provide new service functionalities with the help of more efficient networking, cloud computing and big data processing techniques. Possible new applications may include intelligent traffic status report service, real-time navigation service, inter-vehicle entertainment application, etc.

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